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## ***Compton Suppressed Clover Array for Energy Degraded and Stopped Exotic Beams at RIKEN.***

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Argonne National Laboratory



U.S. Department  
of Energy

UChicago ►  
Argonne<sub>LLC</sub>



Office of  
Science

U.S. DEPARTMENT OF ENERGY

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## *What is an FOA*

### **FINANCIAL ASSISTANCE FUNDING OPPORTUNITY ANNOUNCEMENT**



**U.S. Department of Energy**

**Office of Science  
Office of Nuclear Physics**

**Research Opportunities at Rare Isotope Beam Facilities**

**Funding Opportunity Number: DE-PS02-08ER08-10**

**Announcement Type: Initial**

**CFDA Number: 81.049**

## *Our Proposal*

- Create a pool of Compton suppressed clover detectors from laboratories in Japan and U.S. which can be assembled at RIKEN to be utilized in gamma-ray spectroscopy measurements using both energy degraded ( $<10\text{MeV/nucleon}$ ) and stopped beams of exotic nuclei. This spectrometer would be competitive with clover arrays at ORNL, Ganil, Triumf and IThemba – requires an array  $\sim 16$  CSClovers.
- Physics
  - Multi-Step Coulomb excitation – degree of collectivity
  - Unsafe Coulex, Deep Inelastic Collisions – level structure
  - Fusion Evaporation – high spin
  - Stopped beams – isomers, beta decay,
- Electronics – construct self contained, triggerless acquisition system, instrumented for 20 clover detectors using Gretina digitizers.

## *The FOA Process*

- Phase I – submit pre-application describing the proposed project and its objectives (June, 2008)
- Proposal accepted and collaboration encouraged to submit full proposal (August 2008)
- Workshop held at ANL to discuss full proposal – Dec. 4-5, 2008.
- Phase II – full proposal, submitted 18-December-2008.
- FRIB sited at MSU – December, 2008.
- Outcome of FOA - unknown.

# Japanese Support



Graduate School of Science  
University of Tokyo

## Center for Nuclear Study (CNS)

Dr. Michael P. Carpenter  
Argonne National Laboratory  
Argonne, IL 60439  
USA

May 30, 2008

Dear Dr. Carpenter,

We are excited by the prospect of hosting the Compton Suppressed Ge Clover Array at RIKEN Radioactive Ion Beam Facility (RIBF).

Since RIBF will offer world-unique capabilities with providing extensive species of RI beams of highest intensities, it will open enormous physics opportunities. Studies utilizing gamma-ray spectroscopy will continue to play an important role at RIBF in order to probe nuclear structures of exotic nuclei. Especially the use of stopped and slowed RI beams allows for expanding the detailed spectroscopic studies to new region of nuclear chart employing a variety of experimental techniques established with low-energy stable beam. The Compton suppressed Ge Clover Array will be most fitted to these experiments with stopped and slowed RI beam. Thus such an Ge array combined with RIBF will definitely give us new science opportunities, especially in the field of nuclear structure physics via gamma-ray spectroscopy.

CNS (Center for Nuclear Study, University of Tokyo) has Wako branch inside RIKEN campus. It has been taking an initiative in the high-resolution gamma-ray spectroscopy using Ge detectors. We have been developing energy degraded beams to perform detailed gamma-ray spectroscopy in exotic nuclei. CNS is also taking a primary role in organizing Japanese Gamma-Ray Spectroscopy Association where I have been acting as a chair. Having these research backgrounds, we are glad to be a Japanese host institution to the international collaboration for facilitating operations and progresses of the joint project at RIKEN RIBF. We earnestly hope that the collaboration will be productive to both sides and unite physicists in the field of nuclear structure studies in Japan and United States for a common goal of scientific discovery and understanding.

Sincerely Yours,

Eiichi Ideguchi  
Center for Nuclear Study, University of Tokyo



Dr. Michael P. Carpenter  
Argonne National Laboratory  
Argonne, IL 60439  
USA

May 30, 2008

Dear Dr. Carpenter,

We are very much interested in hosting the research program for nuclear spectroscopy with stopped and energy-degraded RI beams at the RIKEN Radioactive Isotope Beam Factory (RIBF) with Compton suppressed Ge clover array, in strong collaboration with CNS (Center for Nuclear Study, University of Tokyo).

RIKEN RIBF will have unique capabilities in providing beams of a wide range of unstable nuclei (RI beams) either by the fragmentation of heavy ion beams or the in-flight fission of uranium beams with energies of up to 345 MeV/nucleon. Development of stopped and energy-degraded beams might expand much the research opportunities. In combination with the capabilities of Compton suppressed Ge clover detectors, spectroscopic studies quite unique in the world could be performed. Collaborations between scientists from the United State, Japan and possibly other countries would further develop our scientific knowledge.

We are very much glad to work with your group and other collaborators to establish an extensive research program.

Sincerely Yours,

Tohru Motobayashi  
Chief Scientist, RIKEN Nishina Center (RNC)

## ***Current list of Collaborators***

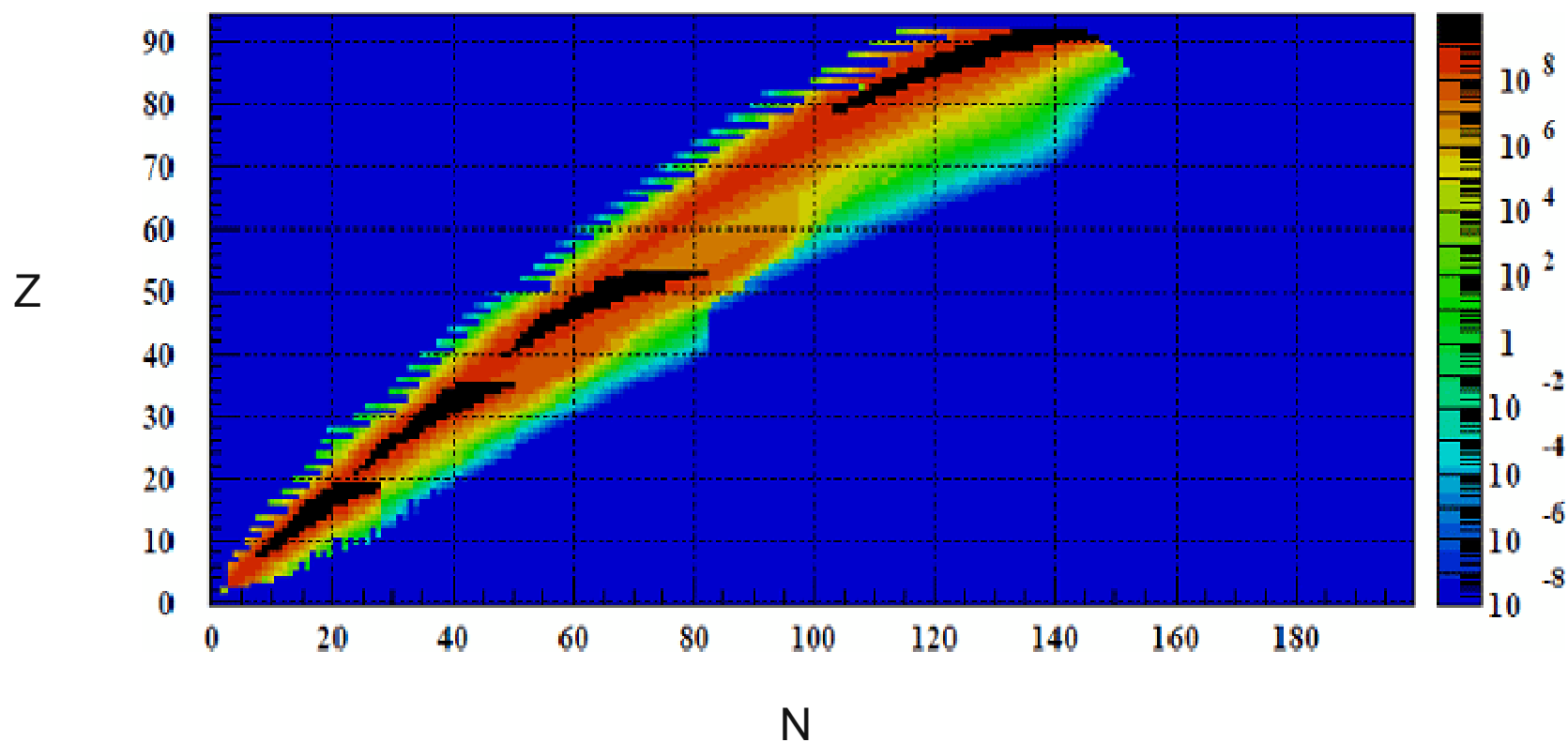
### **USA**

- ANL – M.P. Carpenter, R.V.F. Janssens, C.J. Lister, D. Seweryniak, T.L. Khoo, T. Lauritsen, S. Zhu, F. Kondev, L. McCutchan, C. Chiara
- LBNL – P. Fallon, R. Clark, A. Machiavelli
- ORNL – D. Radford, C.H. Yu
- FSU – S. Tabor, M. Riley, I. Weidenhover
- Yale – R. Casten, V. Werner
- Richmond – C. Beausang
- Wash U. - W. Reviol, D. Sarantities
- Notre Dame – U. Garg
- Naval Academy – D. Hartley
- Miss. State – W. Ma

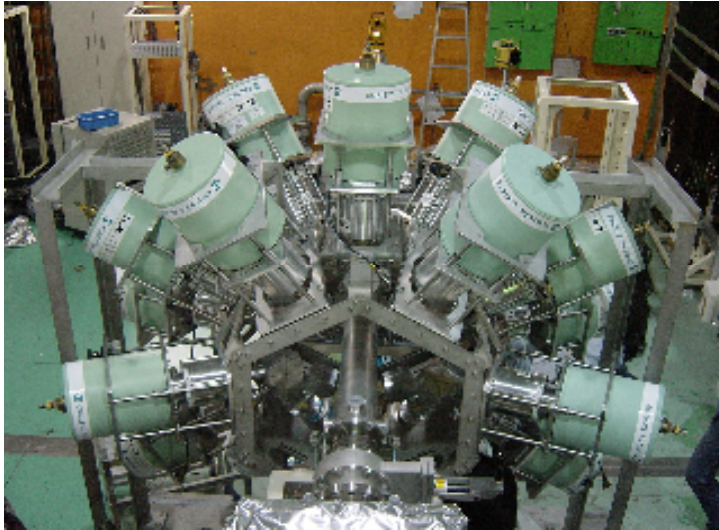
### **Japan**

- CNS, Univ. of Tokyo - E. Ideguchi, S. Shimoura
- RIKEN – N. Aoi, T. Motobayashi, H. Watanabe, S.i Nishimura
- Tohoku University - T. Koike, T. Shinozuka, H. Tamura
- Kyushu University – T. Morikawa
- Tokyo University of Science – T. Sumikama

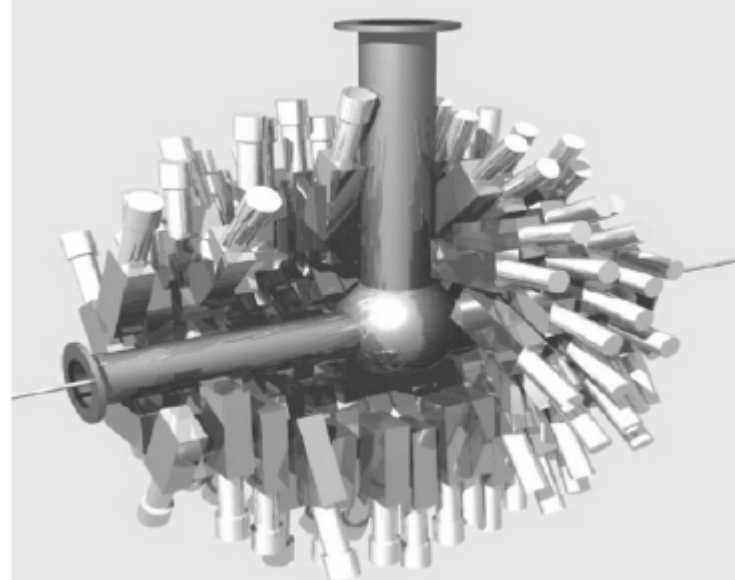
*Expected secondary beam intensities with  
primary beam at  $1\text{p}\mu\text{A}$*



## *Gamma ray arrays @ RIKEN*



GRAPE - Position sensitive Ge planer array ~5% photopeak efficiency.



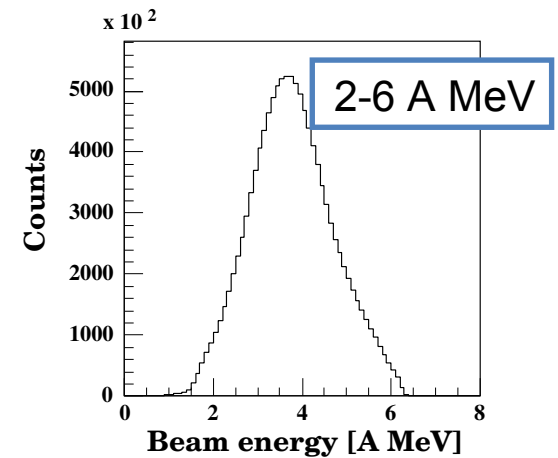
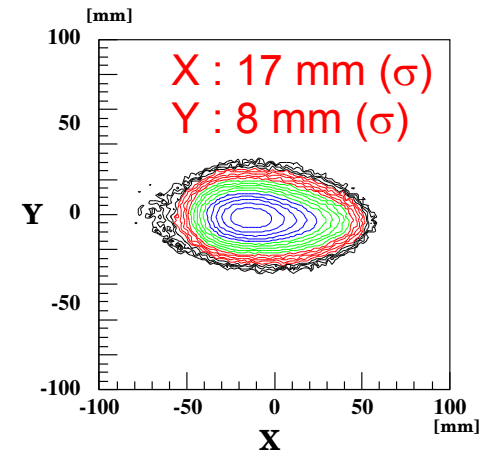
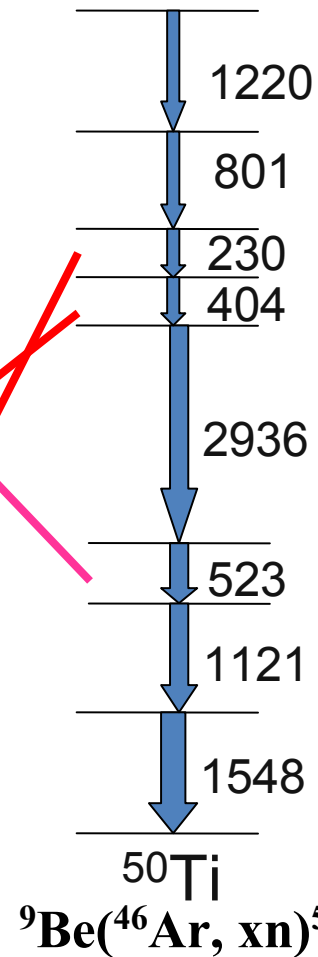
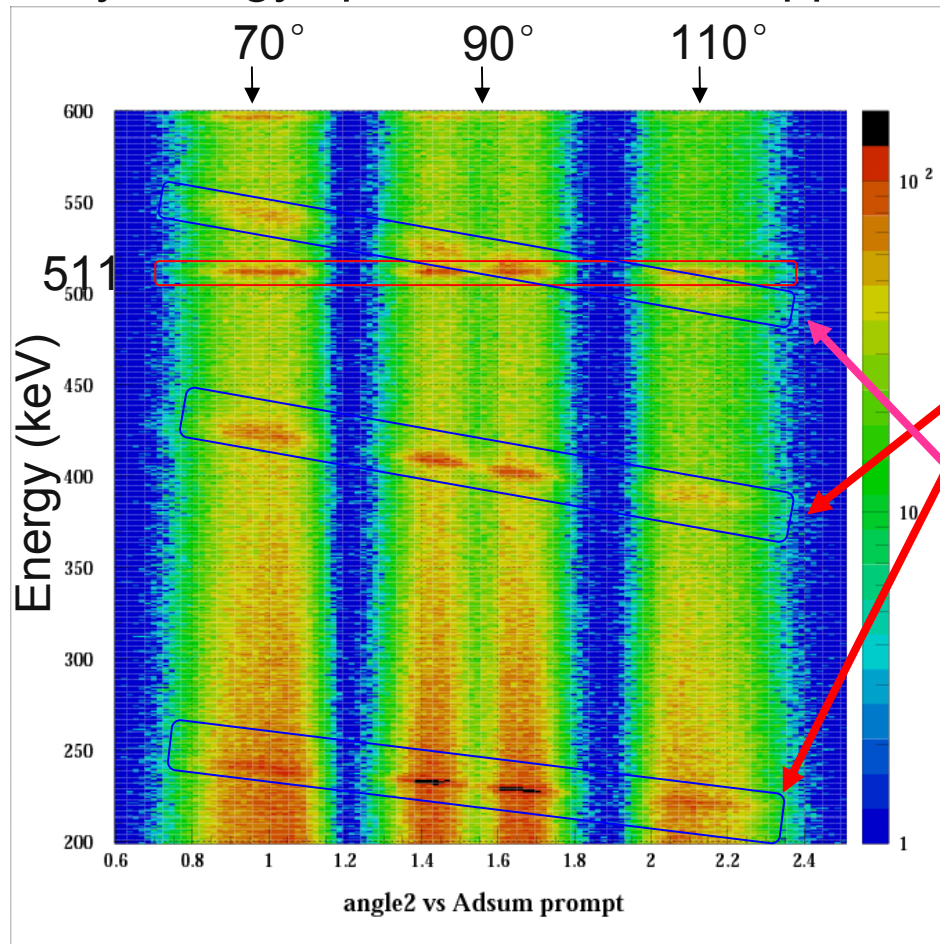
DALI2 – 160 NaI detectors, ~20% photopeak efficiency

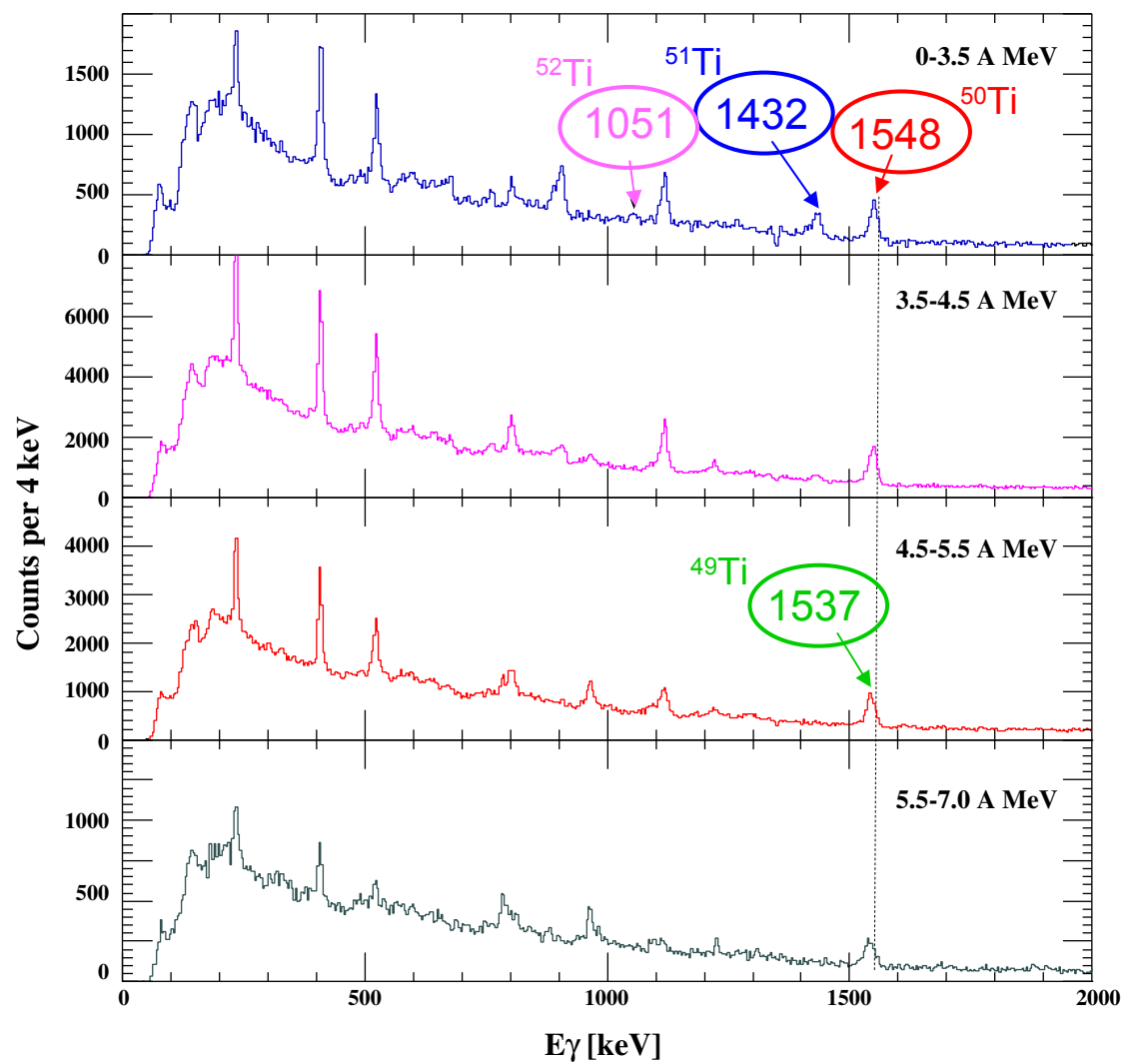
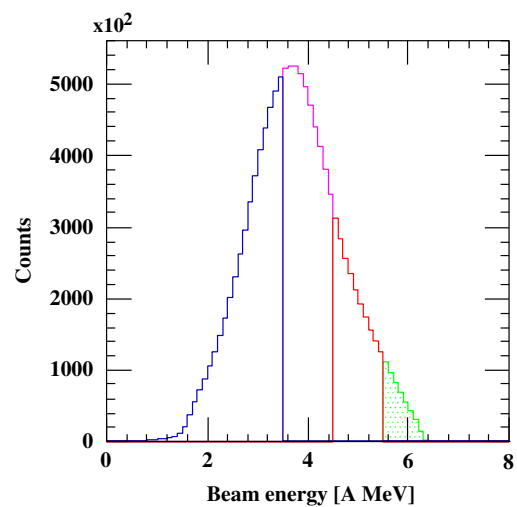
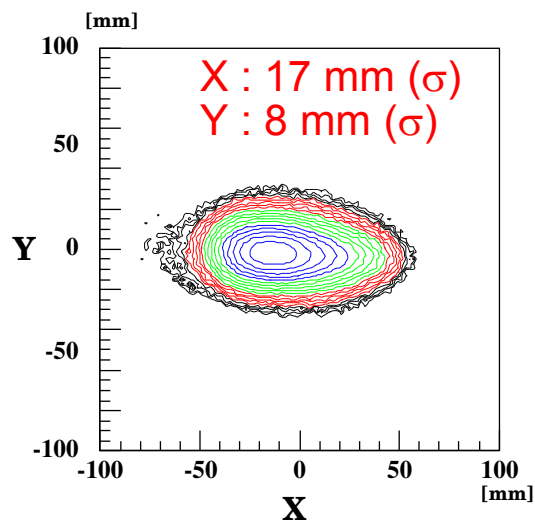
***Both arrays optimized for fast beams.  
Gretina would be U.S. Alternative to Grape  
(large efficiency, tracking, Compton Suppression)***



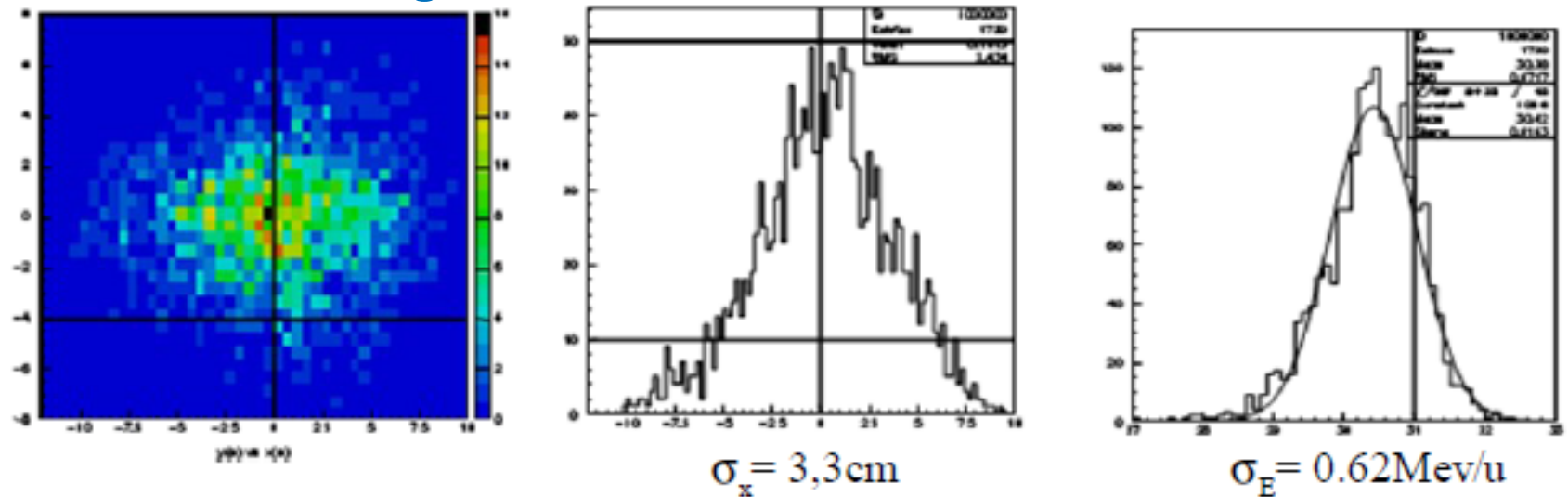
# Doppler Correction with Energy Degraded beam (E. Ideguchi et al., RIPS and GRAPE)

$\gamma$ -ray energy spectrum before Doppler correction

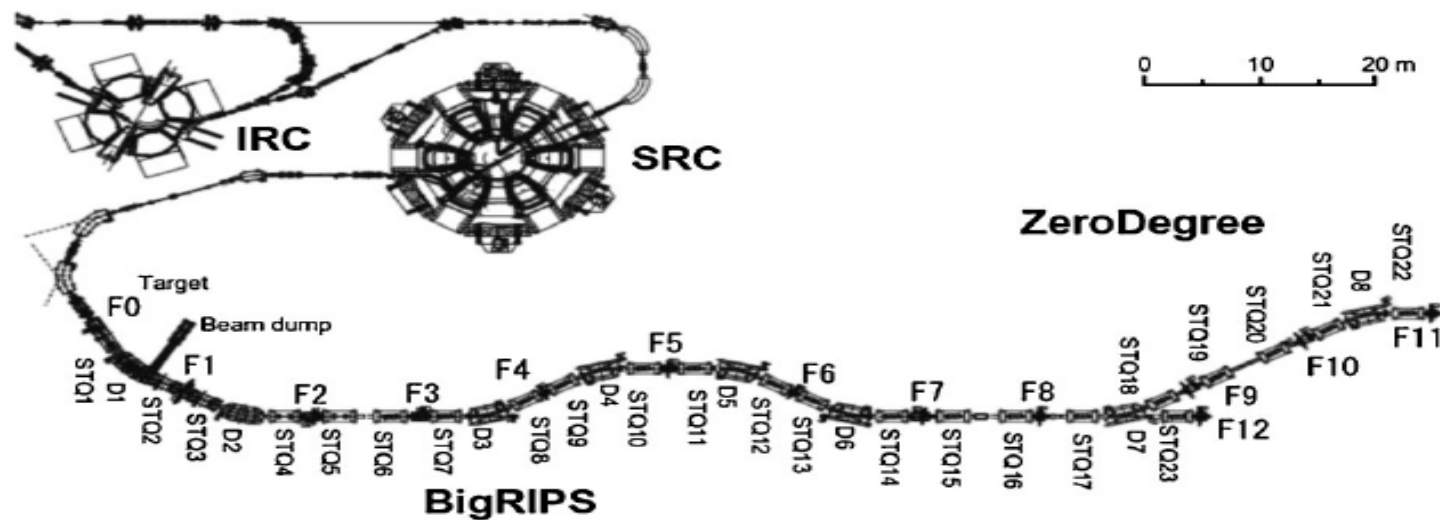




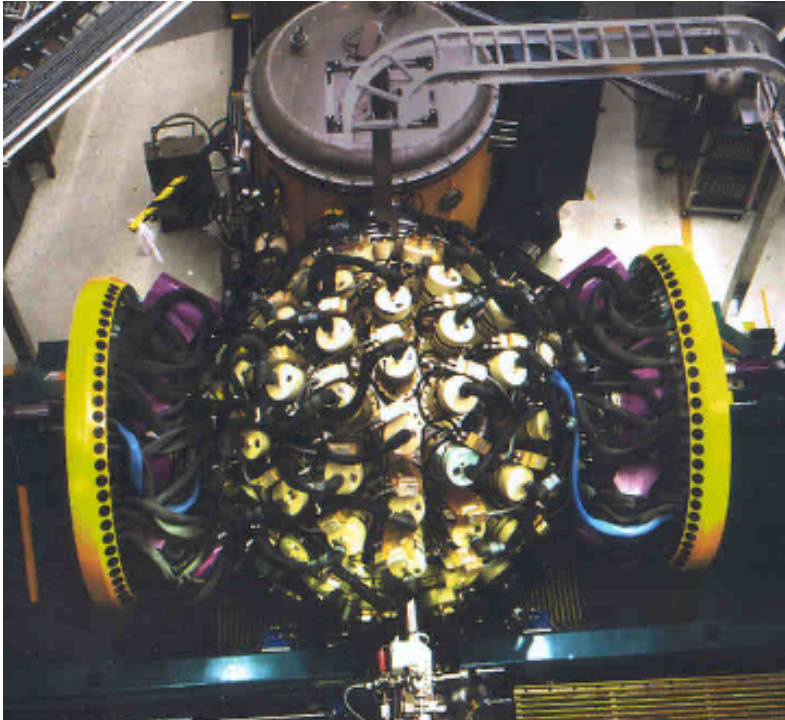
## Simulations for Degraded beams at BIGRIPS



**Figure 8:** Beam profile and energy distribution at F7 obtained from the MOCADI simulation.



## Slow Beam Arrays

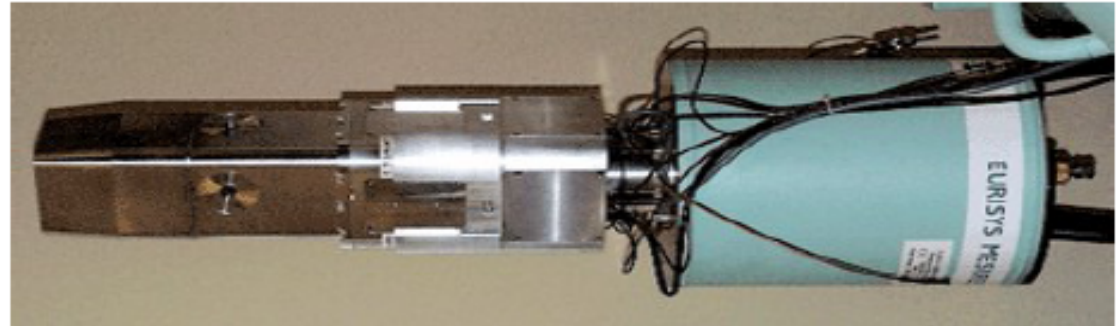
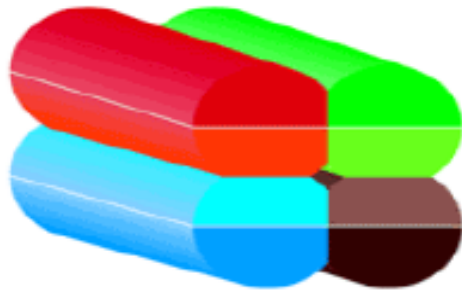


### Gammasphere

- ~10% photopeak efficiency
- Peak/Total  $^{60}\text{Co}$  ~55%
- $4\pi$  coverage
- Requires large lead times for moving and assembly.
- Too costly to duplicate
- Gretina is roughly equivalent to Gammasphere with regards to expected performance for slow beams— earliest availability 2014.

**Alternative:** Clover Array

## *Clover Detectors*



- Large efficiency  $> 100\%$  (relative to 3"x3" NaI)
- 4 crystals provide granularity for improved Doppler reconstruction – advantageous for angular correlations.
- Segmentation of outer contact provides additional segmentation.
- Clovers can be surrounded by anti-Compton shields.
- Can operate as a polarimeter.



## *Available Clovers from the collaboration.*

Institution	Covers	Segmented	Shields
ANL	5	No	No
LBNL	5	Yes	Yes
ORNL	10	Yes	Yes
Yale	10	No	Yes
FSU	3	Yes	Yes
Richmond	1	Yes	Yes
USNA	1	Yes	Yes
RIKEN	5	No	No
Tohoku	6	Yes	Yes
Total	46		

**Fact:** U.S. Clovers play a major role in the experimental program at home institution.

**Goal:** Provide 16 Clover detectors for 3-4 campaigns of 3-4 month duration at RIBF.

**Reality:** Will require long term coordination between institutions.

**Good News:** Pool is oversubscribed by nearly 4 times.

## *Infrastructure (self contained system).*

- Electronics and DAQ
  - Utilize Gretina digitizers (~\$400/ch) and perform Compton suppression in FPGA (under development for Clarion)
  - Gretina Triggering modules (J. Anderson – ANL)
  - Online display and monitoring (GSSORT)
- H.V. - commercial units.
- Liquid Nitrogen fill system – duplicate GRETINA system (D. Radford ORNL)
- Cables
- Frame
  - Design
  - Fabrication (University shop?)
  - How many? (2 would be ideal )
- Computers (slow control, data storage, online monitoring)

## Cost Estimate from Proposal

**Table 3:** Break down of project costs

Type	Description	Cost
Man-power	Engineering design effort (mechanical frame)	\$80,000
	Electronics Engineering effort	\$75,000
Equipment	Support Frame	\$60,000
	LN fill system	\$70,000
	Data acquisition system. 20 Gretina digitizer boards, 3 VME crates, 3 VME processors, 3 trigger modules, signal cables	\$165,000
	HV mainframes and HV cables	\$35,000
	2 Linux based computers, 1 laptop	\$6,000
Travel	6 man/weeks per campaign for setup and dismantling	\$48,000
Operations	Detector Repair and Maintenance	\$50,000
Total		\$719,000

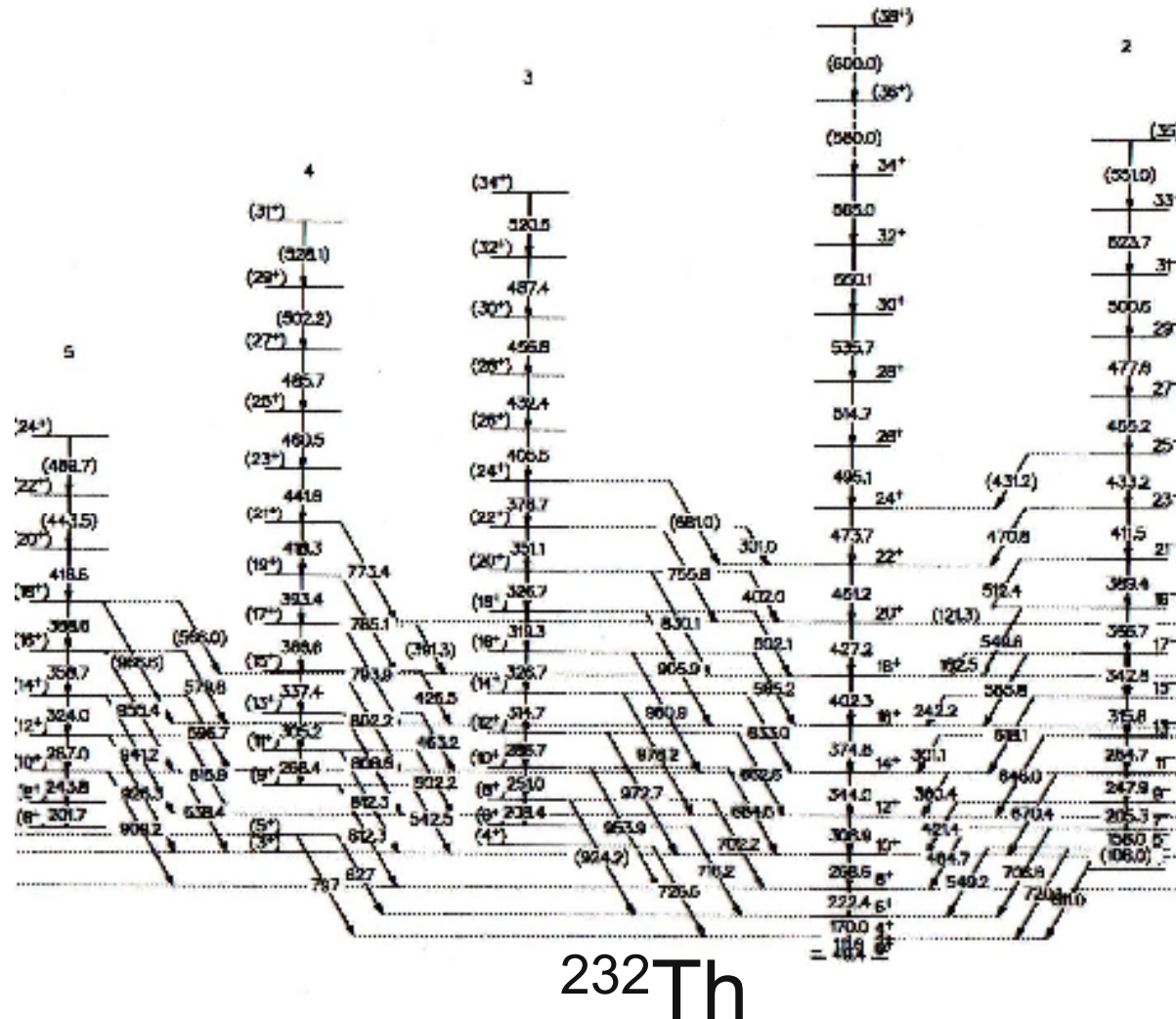


## Schedule

- Need development time for degraded beam from 350 MeV/A to 5 MeV/A.
- Depending on how rapidly we could move – up to four campaigns between 2010-2014 separated by 15 months *i.e.* 3 months on 12 months off.
- The proposed budget gets us into 2014.
- Once the infrastructure is built – campaigns at U.S. Based facilities would also be possible (ORNL, LBNL, Yale, MSU).

## Some Physics at the end

Unsafe Coulex is powerful technique to study deformed nuclei



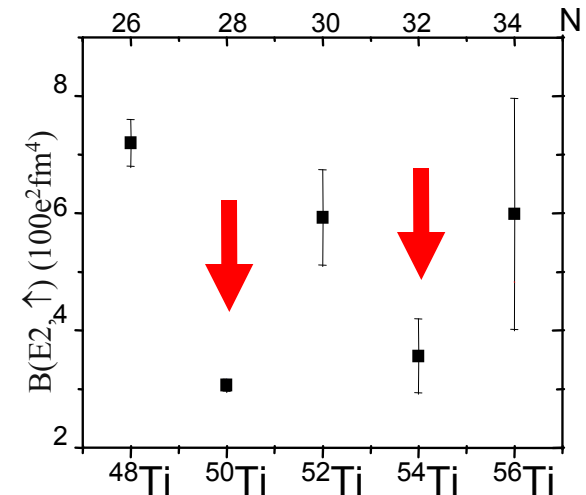
$^{232}\text{Th}$

## Study of excited states allows a fuller picture

28

32

34



D.-C. Dinca *et al.*,  
*PRC 71 041302(R) (2005)*

Fast Beam Coulex  
with Segas @ NSCL

$^{48}Ca + ^{238}U$  DIC with Gammasphere

R.V.F. Janssens *et al.*, *PLB 546*, 22 (2002)

B. Fornal *et al.*, *PRC 70*, 064304(2004)

## *Physics scope highlighted in proposal*

- Island of Inversion – shape coexistence
- Deformed shell gaps in vicinity of  $^{48}\text{Ca}$  –  $4p4h$  &  $8p8h$  ( $^{40}\text{Ca}$ )
- Neutron rich  $A \sim 100$  region – shape coexistence (CARIBU)
- Octupole collectivity in neutron rich Ba region (CARIBU)
- Evolution of deformation around “doubly mid-shell”  $^{170}\text{Dy}$ .
- Stopped beams – isomers in  $^{132}\text{Sn}$  region.

## *$^{32}\text{Mg}$ is a good case for this array.*

Expected beam intensities for 2009 (pnA)

Isotope	$^{48}\text{Ca}$	Kr	Xe	$^{238}\text{U}$
Now	30-50	30-50	5-10	0.3-0.5
April 2009	200	100	20	5

	$^{48}\text{Ca}$	Kr	Xe	U(frag)	U(fiss)
$^{32}\text{Mg}$	5.4e5	2.0e3	1.2e2	6.2e2	2.0e1

**Table 2:** Expected yields in particles/sec at the BIGRIPS focal plane for neutron-rich Mg isotopes following the fragmentation at 350MeV/A of 200pnA  $^{48}\text{Ca}$ .

$^{28}\text{Mg}$	$^{29}\text{Mg}$	$^{30}\text{Mg}$	$^{31}\text{Mg}$	$^{32}\text{Mg}$	$^{33}\text{Mg}$	$^{34}\text{Mg}$
$2 \times 10^8$	$6.2 \times 10^7$	$1.5 \times 10^7$	$3.0 \times 10^6$	$5.4 \times 10^5$	$8.4 \times 10^4$	$1.2 \times 10^4$

## *Status and Outlook*

- Waiting for FOA decision
- A negative decision on funding should not kill project.
- Need to begin to seriously about short and long term collaboration.